Chapter XXI

METRIC CONVERSION

ENGLISH SYSTEM[1]

Weights and measures were among the earliest tools invented by man. The measurement system commonly used in the United States today is nearly the same as that brought by the colonists from Enland. These measures had their origins in a variety of cultures - Babylonian, Egyptian, Roman, Anglo-Saxon, and Norman-French. England, by the 18th century, had achieved a greater degree of weights and measures standardization than the Continental countries. Through colonization and dominance of world commerce during the 17th, 18th, and 19th centuries, the English system of weights and measures was spread to and established in many parts of the world. In the United States, the need for greater standards uniformity led to clauses being ratified in the Articles of Confederation and the Constitution giving power to Congress to fix uniform standards for weights and measures. Today, the National Bureau of Standards supplies these standards to all states to assure uniformity throughout the country.

METRIC SYSTEM

The Flemish mathematician, Simon Stevin proposed a universal decimal system of measurement in 1585 but his efforts for adoption were unsuccessful. In 1790, the National Assembly of France requested the French Academy of Sciences to "deduce an invariable standard for all the measures and all the weights". The commission appointed by the Academy created the Metric system.

Use of the Metric system was made compulsory in France in 1840. The standardized character and decimal features of the system made it well suited to scientific and engineering work.

During 1875, an international treaty, the "Treaty of the Meter", signed by 17 countries and the United States, set up well defined metric standards for length and mass, and the procedures to recommend and adopt further refinements to this system. The General Conference of Weights and Measures, the diplomatic organization made up of adherents to the Treaty, meets periodically to ratify improvements in the system and standards.

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In 1960, the General Conference adopted an extensive revision and simplification of the Metric system. This revision was named Le Systemé International d'Unitès, with the international abbreviation SI being adopted.

Further improvements were made by the General Conference in 1964, 1968, and 1971. All of the major industrialized nations of the world except the United States have converted to the International System of Units (SI). Some manufacturing plants in the United States are now using or converting to the SI units.

The following material is presented as a guide for uniformly incorporating the International Systems of Units (SI) and English units where it is desired to communicate in units of both measurement systems. More information on SI units are contained in a book by LeMaraic and Ciaramella.[2]

INTERNATIONAL SYSTEM OF UNITS (SI)

The International System of Units, SI (Système International d'Unités) is a rationalized selection of units from the metric system. The system is decimalized, based on multiples of 10, except for time in the traditional second. For example, the basic unit of length is the meter; the longer unit is the kilometer (1000 meters), and shorter units are the decimeter (0.1 meter), the centimeter (0.01 meter), the millimeter (0.001 meter), etc. The SI system is coherent, so conversion factors are unnecessary when all units are SI. This system will eliminate the need of the varying conversion factors of English units such as 12 inches per foot, 43,560 square feet per acre, or the 7.48 gallons per cubic foot, etc.

The system consists of seven basic units, two supplementary units and a series of derived units. The derived units are based on single basic units i.e., one newton is the force required to accelerate one kilogram of mass one meter per second per second. Tables XXI-1 through XXI-8 include the basic and some of the derived units used.

TABLE XXI-1
Basic SI Units and Symbols[1]

Quantity	Unit	SI Symbol
Length	meter	m
Mass	kilogram	kg
Time	second	s
Electric current	ampere	A
Thermodynamic temperature	degree Kelvin	°K
Luminous intensity	candela	cd
Amount of a substance	mole	mol

The basic unit of length is the meter. The strictest use of SI would discourage multiple and sub-multiple unit prefixes other than those divisible by 3 (i.e., 10^3, 10^{-6}, etc.). The centimeter will probably remain in common use because it is a convenient dimension relative to the visible world. Therefore, it is included in the English/SI Conversion Factors Table for length, area, and pressure (Table XXI-6).

The strict and correct use of mass (kilogram) and force (newton) should avoid much confusion associated with the use of pound force, pound mass, kilogram force, and kilogram mass systems. It will remove the use of force units for density.

TABLE XXI-2
Supplementary SI Units

Quantity	Metric Unit	SI Symbol
Plane angle	radian	rad
Solid angle	steradian	sr

TABLE XXI-3
Multiple and Submultiple Unit Prefixes[1]

Multiplication Factors	Prefix	SI Symbol
1,000 000 000 000 = 10^{12}	tera	T
1,000 000 000 = 10^9	giga	G
1,000 000 = 10^6	mega	M
1,000 = 10^3	kilo	k
100 = 10^2	hecto	h
10 = 10^1	deka	da
0.1 = 10^{-1}	deci	d
0.01 = 10^{-2}	centi	c
0.001 = 10^{-3}	milli	m
0.000 001 = 10^{-6}	micro	u
0.000 000 001 = 10^{-9}	nano	n
0.000 000 000 001 = 10^{-12}	pico	p
0.000 000 000 000 001 = 10^{-15}	femto	f
0.000 000 000 000 000 001 = 10^{-18}	atto	a

TABLE XXI-4
Some Derived SI Units

Quantity	Unit	SI Symbol	SI Unit
acceleration	meter per second squared	—	m/s²
angular acceleration	radian per second squared	—	rad/s²
angular velocity	radian per second	—	rad/s
area	square meter	—	m²
density	kilogram per cubic meter	—	kg/m³
electrical capacitance	farad	F	A•s/V
electrical conductance	siemens	S	A/V
electrical field strength	volt per meter	—	V/m
electrical inductance	henry	H	V•s/A
electrical potential difference	volt	V	W/A
electrical resistance	ohm	Ω	V/A
electromotive force	volt	V	W/A
energy	joule	J	N•m
force	newton	N	kg•m/s²
frequency	hertz	Hz	(cycle) /s
illuminance	lux	lx	lm/m²
luminance	candela per square meter	—	cd/m²
luminous flux	lumen	lm	cd sr
magnetic field strength	ampere per meter	—	A/m
magnetic flux	weber	Wb	V•s
magnetic flux density	tesla	T	Wb/m²
magnetomotive force	ampere	A	—
power	watt	W	J/s
pressure	pascal	Pa	N/m²
quantity of electricity	coulomb	C	A•s
quantity of heat	joule	J	N•m
radiant intensity	watt per steradian	—	W/sr
specific heat	joule per kilogram-kelvin	—	j/kg•K
stress	pascal	Pa	N/m²
thermal conductivity	watt per meter-kelvin	—	W/m•K
velocity	meter per second	—	m/s
viscosity, dynamic	pascal-second	—	Pa•s
viscosity, kinematic	square meter per second	—	m²/s
voltage	volt	V	W/A
volume	cubic meter	—	m³
work	joule	J	N•m

Use of Derived Units

The use of watts (and kilowatts, kW) for power will allow the direct calculation of power needed for electric motors, and present a convenient comparison between electrical motors and combustion engines. Since 1 kW ≅ 1.34 HP the actual magnitude of the numbers used to represent power will not change drastically.

The customary temperature scale when dealing with water is in degrees Celsius (°C), where 0° C is the freezing temperature and 100° C the boiling point of water at sea level (°C = K - 273.15).

While the recommended unit of pressure is the Pascal, sprinkler pressures may be more conveniently expressed in newtons per square centimeter (1 psi ≅ 0.69 N cm^{-2}, 6.89 kN m^{-2}). Thus, a recommended sprinkler pressure of 58 psi would be 40 N cm^2. A bar (equal to 10 N cm^{-2}), which is approximately equal to one atmosphere, will continue to be used in soil moisture tension or potential measurements.

It is often necessary to relate differences in elevation and pressure when considering pumping plants. In this case, the mass (kg) of water above an area (cm^2) is multiplied by the acceleration due to gravity (about 9.8 m s^{-2}) to obtain the pressure (N cm^{-2}). This results in 1 meter of water equalling about 0.98 N cm^{-2} or roughly 1 m water ≅ 1N cm^{-2}, a very convenient relationship.

TABLE XXI-5
Units Used in Conjunction with SI

Quantity	Metric Unit	SI Symbol	SI Unit
Area	hectare	ha	$10^4 m^2$
	dekare	daa	$10^3 m^2$
Volume	liter	l	$10^{-3} m^3 = dm^3$
Pressure	bar	bar	$10^5 N\ m^{-2} = 10\ N\ cm^{-2}$
Mass	ton	t	10^3 kg = Megagrams

Crop yields are reported as mass per unit area. The customary system for expressing yield on a volume basis necessitates knowing the unit weight (pounds per bushel) for each crop considered. Actually, the mass is measured and converted to volume (bushels) via the unit weight standard and then converted back to a mass unit (pounds mass) when the crop is sold, consumed, or used to form rations. A uniform reporting of all yields in mass per unit area (kg daa^{-1}, kg ha^{-1} or t ha^{-1}) would greatly simplify many calculations concerning the production and disposal of the crop.

The dekare (equal to one dunam; 1 acre ≅ 4 dekare) as a unit of land area is included in Table XXI-5 because it will be preferred to the hectare in many cases. A dekare is equal to 1000 m^2 ($10^3 m^2$). Advantages include 1 kg m^{-2} = 1 ton daa^{-1}, which is convenient for checking yields or conducting plot work, and 1 mm depth of water over 1 daa = 10^3l or 1 m^3, which is convenient for calculating crop water requirements and water flow and storage.

TABLE XXI-6
English/SI Conversion Factors

Multiply	by	to obtain	Multiply	by	to obtain
Length					
millimeter	0.0394	inch	inch	25.4*	millimeter
centimeter	0.3937	inch	inch	2.54*	centimeter
meter	3.281	foot	foot	0.3048	meter
kilometer	0.6215	mile	mile	1.609	kilometer
Area					
centimeter^2	0.155	inch^2	inch^2	6.452	centimeter^2
meter^2	10.764	foot^2	foot^2	0.0929	meter^2
dekare	0.2471	acre	acre	4.046	dekare
hectare	2.471	acre	acre	0.4046	hectare
Volume					
liter	0.264	U.S. gallon	U.S. gallon	3.785	liter
liter	0.2198	Imperial gallon	Imperial gallon	4.546	liter
meter^3	264.20	U.S. gallon	U.S. gallon	0.003785	meter^3
meter^3	219.22	Imperial gallon	Imperial gallon	0.004546	meter^3
meter^3	35.315	foot^3	foot^3	0.0283	meter^3
meter^3	0.00081	acre foot	acre foot	1,233.5	meter^3
Mass					
kilogram	0.06852	slug	slug	14.594	kilogram
kilogram	2.2046	pound mass	pound mass	0.4536	kilogram
ton (SI) = 1000 kg	1.1023	ton mass (2000 lbs)	ton mass (2000 lbs)	0.9072	ton (SI) = 1000 kg
Force					
newton	0.2248	pound force	pound force	4.448	newton
Energy					
joule	0.000947	BTU	BTU	1055.87	joule
Power					
watt	0.00134	horsepower (550 ft lb force^{-1})	horsepower (550 ft lb force^{-1})	745.7	watt
watt	0.00134	horsepower electric	horsepower electric	746	watt
Pressure					
newton centimeter^{-2}	1.4504	psi	psi	0.6895	newtons centimeter^{-2}
newton centimeter^{-2}	0.0987	atmosphere	atmosphere	10.1325	newtons centimeter^{-2}
bar	0.987	atmosphere	atmosphere	1.0132	bar
Flow					
meter^3 second^{-1}	35.311	feet^3 second^{-1}	feet^3 second^{-1}	0.02832	meter^3 second^{-1}
liter second^{-1}	15.85	gallon minute^{-1}	gallon minute^{-1}	0.06309	liter second^{-1}
Density					
kilogram meter^{-3}	0.06243	pound mass foot^{-3}	pound mass foot^{-3}	16.018	kilogram meter^{-3}
Velocity					
meter second^{-1}	3.281	feet second^{-1}	feet second^{-1}	0.3048	meter second^{-1}

*Exact

Notation and Conversion

SI symbols of units are in lower case Roman type except for those derived from proper names in which case capital Roman type is used. Unit symbols do not change in the plural. Because the lower case symbol for liter (l) could sometimes be confused with the number 1 in typed or printed matter, it has been recommended that a "script *l* " be used for this purpose.[2]

SI symbols are never followed by a dot as is used in contractions as sq., in., etc.

A solidus (oblique stroke, /), a horizontal line, or negative powers may be used to express a derived unit formed from two others by division. For example:

$$\mathrm{m/s}, \text{ or } \frac{\mathrm{m}}{\mathrm{s}} \text{ or } \mathrm{m} \bullet \mathrm{s}^{-1}$$

Only one solidus should be used in a combination of units unless parentheses are used to avoid ambiguity.

Metric countries have adopted the comma rather than the British dot as the decimal indicator, 13,6 kg.

Numbers may be divided into groups of three by means of spaces counting from the decimal indicator as in Table XXI-3. Commas are never inserted in the spaces between the groups.

Conversion Factors

Caution should be exercised when converting to SI values. The precision of the original value must be maintained as closely as possible. However, excessive precision should not be implied by using more significant figures than are warranted by the original value.

The following table of conversion factors (XXI-6) is included for the convenience of those who must convert customary to SI values or vice versa.

The following tables are included to provide a convenient conversion for nozzle size and pressure between SI and English units.

TABLE XXI-7
SI to English Pressure Equivalents

Newton centimeter^2	Pound inch^2
10	14.5
15	21.8
20	29.0
25	36.3
30	43.5
35	50.8
40	58.0
45	65.3
50	72.5
55	79.8
60	87.0
65	95.3
70	101.5

Miscellaneous Quantities

Acceleration due to gravity (g)	$9.806\ m\ s^{-2}$
Kinematic Viscosity (water, 20° C)	$15.29 \times 10^{-6} m^2 s^{-1}$
Dynamic Viscosity (water, 20° C)	$18.8 \times 10^{-6} kg\ m^{-1} s^{-1}$

TABLE XXI-8
Inch to Millimeter Equivalents for Sprinkler Nozzles

Inch				
8ths	16ths	32nds	64ths	Millimeters
			1	0.3969
		1	2	0.7938
			3	1.1906
	1	2	4	1.5875
			5	1.9844
		3	6	2.3813
			7	2.7781
1	2	4	8	3.1750*
			9	3.5719
		5	10	3.9688
			11	4.3656
	3	6	12	4.7625
			13	5.1594
		7	14	5.5563
			15	5.9531
2	4	8	16	6.3500*
3	6	12	24	9.5250*
4	8	16	32	12.7000*

*Precision to three significant figures.